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PATTERN RECOGNITION ON
PANCHROMATIC AERIAL PHOTOGRAPHS IN
NORTHERN TERRAIN

by

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ABSTRACT

For general purpose location engineering, under daylight conditions in the Arctic, there is no better single approach than the airphoto interpretation of conventional panchromatic film. The interpretation of aerial photography is one of the most economical ways of obtaining information concerning terrain sensitivity in the north.

This paper deals with a brief description of the relationship of topography, vegetation and drainage upon the distribution of permafrost in the discontinuous zone and the location of the least detrimentally frozen ground in the continuous zone.

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PATTERN RECOGNITION FROM AVAILABLE PHOTOGRAPHS

Introduction

The rapid development of resources, transportation networks and townsites in Northern Canada, necessitates a systematic approach to minimize the subsequent stresses placed on the environment. Stresses induced upon permafrost-affected terrain have shown it to be "terrain sensitive".

Any geographical location can be classified as "terrain sensitive" if under normal land use activity the surficial material fails under bearing load or as a result of loading. This failure can be either immediate or as a result of land use activity which has disturbed the existing equilibrium.

The stresses on the environment, which necessarily accompany development, can be minimized through the discriminant identification and avoidance of terrain sensitive land units. The correlation of surficial pattern elements as recorded on aerial photography with known ground conditions by an experienced photo interpreter can be used to arrive at a systematic qualitative classification of

terrain sensitivity. The photo interpreter must be able to evaluate such features as landform, drainage pattern, gully shapes, tone, texture and vegetation which combine to form a unique pattern on the photograph. With backgrounds as various as geology, pedology, forestry, geography or climatology, the experienced photo interpreter will be able to infer soil type, parent material, depth of overburden, moisture content, and occurrence of permafrost. The amount of information and its validity depends on the background and experience of the photo interpreter.

It is difficult to obtain quantitative information on terrain sensitivity but qualitative information can be inferred from aerial photographs. The interpretation of aerial photographs is one of the most economical ways of obtaining information on the Arctic.

The subsurface soil conditions are important to a civil engineer responsible for site selection in any latitude. All structures must be founded on soil capable of supporting the bearing load and requiring a minimum of maintenance. Historically the approach to northern development has been to progress northward using the same construction techniques used in southern temperate climes. The engineer responsible for route selection procedures has found that changes in site selection techniques with corresponding changes in design are necessary with increasing

latitude. Basically two changes in the approach to route selection must be observed. The first occurs with the change from temperate climatic conditions to those of the Subarctic with the attendant permafrost terrain. The second occurs with increasing latitude as the continuous permafrost region is encountered.

This paper is divided into two sections dealing with, (a) the discontinuous permafrost zone; (b) the continuous permafrost zone. The identification of terrain units from aerial photography, based upon the three elements, topography, vegetation and drainage, can be used as a preliminary guide to the evaluation of Arctic terrain.

A. The Discontinuous Permafrost Zone

It must be noted that the aerial photograph accurately records only those natural and cultural features on the earth's surface which are visible to the camera, taking into account problems of sun angle, haze, shadow, etc. The most useful photography is available photography. Black and white (panchromatic) aerial photographs are available for all regions of Canada from the National Air Photo Library, Surveys and Mapping Branch, Department of Energy, Mines and Resources, and in some instances from aerial survey companies who have completed an aerial survey of a region. A description of supplemental aerial photography other than black and white will not be discussed in this paper.

The introduction mentions the necessity of altering route selection procedures with increasing latitude. The occurrence of the permafrost environment causes this change in route location procedures. Normally, route location based upon economic considerations, results in the shortest corridor selection between points "A" and "B". However, with a thorough understanding of surface patterns, the location engineer, conscious of economics selects his route to minimize the amount of permafrost-affected terrain encountered, resulting in lower maintenance costs. The number of surface manifestations of permafrost in the discontinuous zone is far fewer than the numerous permafrost indicators in the continuous zone. Knowledge of permafrost indicators combined with a thorough understanding of the identifiable pattern elements and their relationship to the distribution of permafrost will allow the delineation of the best route.

The pattern elements, which are the basis for the discriminant analysis of airphotos, are evaluated by a detailed examination of two overlapping aerial photographs, thus permitting a stereoscopic view of the terrain. Topography, vegetation and drainage are the three principle pattern elements used for terrain analysis.

A.1 Topography

The topography of the discontinuous permafrost region varies with geographic position and is strongly influenced by its physiographic location and glacial history. Regionally the discontinuous permafrost zone is divided into four major physiographic regions: the Canadian Shield; the Hudson Bay Lowlands; the Interior Plains

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and the Cordillera. (Physiographic Map of Canada 1254A). The Canadian Shield predominates the majority of the discontinuous zone between the Hudson Bay Lowlands and the Interior Plains. The topography consists of rock outcrops containing poorly drained depressions. The soil of the region is glacial in origin and has a thin overburden depth in proximity to the rock outcrops and is overlain with organic material in the depressions. The distribution of permafrost in these areas occurs mainly in the better drained peat bogs in the south and becomes more widespread in the north. The location engineer should try to avoid well drained low lying depressions which possibly will contain permafrost islands.

The smallest physiographic region affected by the discontinuous zone is the Hudson Bay Lowland. This entire region coincides approximately with the geomorphic sub-division on the Glacial Map of Canada of maximum marine overlap. This area is a low flat area with strand lines, visible on the aerial photographs, marking the limits of post-glacial flooding. The parent material consists predominantly of lacustrine materials overlain with muskeg deposits. This area contains the topographic microfeatures

which are the most reliable indicators of permafrost. These local microrelief features institute the accumulation of peat in plateaux or palsas (a Swedish term for a low hill or knoll in peatland containing permafrost). These elevated features are normally one or more metres high and are very well drained compared to the surrounding terrain. As a result of their topographically higher position, it is assumed that there is less snow cover in the winter acting as insulation which explains the occurrence of permafrost. "Peat plateaux and palsas appear as small white irregular shapes covered with a dense spruce forest and ground cover of hummocky, thick sphagnum and other mosses, lichens and Labrador tea" on aerial photographs. (Brown 1968).

The Interior Plains lie between the Canadian Shield and the Cordillera. This area, similar to the Hudson Bay lowlands, was inundated as a result of glacial lake ponding due to the Wisconsin Laurentide ice sheet. The topography has been smoothed by glaciation and a cover of fine-grained lacustrine soils predominates this region. Similar to the other regions, permafrost is found in peat plateaux and palsas in the south and becomes more widespread in the north.

The Cordillera is the western boundary to the discontinuous permafrost zone. Permafrost found in the Cordillera is influenced as much by altitude as by climate, which is geographically controlled. The distribution of permafrost is complicated by varying slope and aspect associated with this mountainous region.

At Cassiar, near the 60th parallel, which is climatically in the southern fringe of the discontinuous permafrost zone, no permafrost occurs at the townsite. The townsite is located in an area devoid of peat bogs on the valley floor of the gravel outwash area. (Brown 1968).

The preceeding example illustrates that a thorough understanding of topographic form can aid in site selection.

A.2 Vegetation

Vegetation is a climate-controlled feature which constantly changes from south to north. The regional identification of terrain units on the basis of airphoto interpretation is limited because of the effects caused by varying local climatic conditions. The attempt to develop a key relationship between cover type and permafrost distribution has met with limited success. Attempts have been made to correlate the distribution of lichen in peat terrain with the occurrence of permafrost. (Korpijaako 1966). These attempts have been based on trying to describe the southern limit of permafrost based on the percentage of lichen cover type. Radforth noted that "aerial inspection on flights from south to north reveal EI changing to EH and finally HE" and concluded that the increasing importance of the "H factor" pointed to some relationship to the southern limit of permafrost. (Radforth 1962). The letters mentioned (EI, EH and HE) refer to Radforth's Organic Terrain Classification System which is based on a minimum of twenty-five percent cover type. Radforth, on the basis of his preliminary observation, concluded that the H-factor, increasing lichen cover, (as one index) points to the existence of subsurface ice. (Radforth 1966).

Field observations conducted by Dr. R.J.E. Brown of the Division of Building Research, National Research Council revealled no apparent definitive relationship between the occurrence of permafrost and the H-factor. Dr. Brown did however conclude that "the presence of well-drained peat appears to be a necessary prerequisite for permafrost". (Brown 1965).

Regionally, there does not appear to be any correlation between vegetation and permafrost since the cover type established on a particular site reflects the total affect of environment on which climate and subsurface conditions are but two factors. Locally, the distribution of a plant can be influenced by a single limiting factor. Airphoto interpretation techniques, although dependent on a regional similarity of terrain unit identification, may however, be able to arrive at an inference of the areal distribution of permafrost through an assessment of a smaller or local area.

The density and height of trees, identifiable by the airphoto interpreter, have an important effect on the thermal energy balance of the area. Wind speeds are lower in areas of dense growth than in areas having scattered trees or over low bog regions. In these bog areas, the winds are higher and there is more heat carried away per unit time than in the higher areas with better vegetation. (Johnston, et al, 1963).

Some investigators (Hopkins and Karlstrom 1955) have attempted to relate xerophytes and phreatophytes with the distribution of permafrost. Xerophyotes, such as larch and black spruce, indicate permafrost near the surface, because of their shallow root system. Tall willows and mature aspen which usually grow on poorly drained flood plain regions have a deeper root system (phreatophytes) and can be used as one indicator of the probable absence of permafrost.

The distribution pattern of trees in the discontinuous permafrost zone can only be used as one indicator of permafrost and is most useful when evaluated with other information.

A.3 Drainage

Hydrologic phenomena identified on aerial photography can be used to predict subsurface ground conditions. The drainage characteristics, which reflect parent material type, change with increasing latitude and can be used to reliably predict the absence or presence of permafrost affected terrain.

The presence of permafrost can be related to the occurrence of peat plateaux or palsas; however, where peat micro-relief features are absent, the existence of permafrost can only be inferred from other visible patterns such as drainage.

Dr. R.J.E. Brown (1970) states that the ponding of water deters the presence of permafrost. It is very

unlikely that permafrost will be found in wet reed or sedge meadows in the southern fringe of the discontinuous zone or along the flood plains of any major river. Permafrost surrounding these water-inundated depressions would likely thaw if the amount of water were to increase and cause flooding of the surrounding regions.

Regional drainage is usually influenced more by landform than by the presence of permafrost; whereas local drainage conditions are usually affected by permafrost conditions. Aerial photographs can be used to locate the natural drainage courses. Any change in these courses can be observed on time sequented photography.

The effect permafrost has on the hydrological regime cannot be ignored in engineering design and location. The many shallow ponds and lakes in the northern part of the discontinuous zone, along with "beaded streams", can be used as an indication of the influence of permafrost.

Locally unfrozen zones within permafrost areas may be inferred from the more luxuriant vegetation occurring in a pronounced linear pattern. These unfrozen zones may be useful as a source of ground water in a region where most of the lakes greeze to the bottom. Other hydrological features can be used to outline areas free of permafrost in the discontinuous zone. "Abrupt decrease in stream

discharge as it crosses permeable areas, large streams that end in small lakes, or ponds that lack outlets and unusually large fluctuations of lake levels would all suggest active infiltration into the subsurface and hence the possibility that the areas are not frozen even at some depth". (Hopkins et al, 1955).

In general, the surface drainage pattern in the discontinuous zone on a regional basis is not affected by permafrost but local conditions can reveal ground ice. The thawing effect of ponded or running water is remarkably large because of the high heat storage capacity.

B. The Continuous Permafrost Zone

The continuous zone, in contrast to the discontinuous zone, exists as an area where permafrost is found everywhere, (except in newly deposited unconsolidated sediments where the climate has just begun to impose its influence on the ground thermal regime (Brown 1968, pg. 8)) and generally to great depth beneath the ground surface.

The increasing areal distribution and thickness of permafrost is represented in Figure 1, "Profile of Permafrost Conditions".

Independent of topography, vegetation and drainage, perhaps the single most important factor affecting the distribution of permafrost is climate. The most easily measured climatic factor is temperature. Therefore,

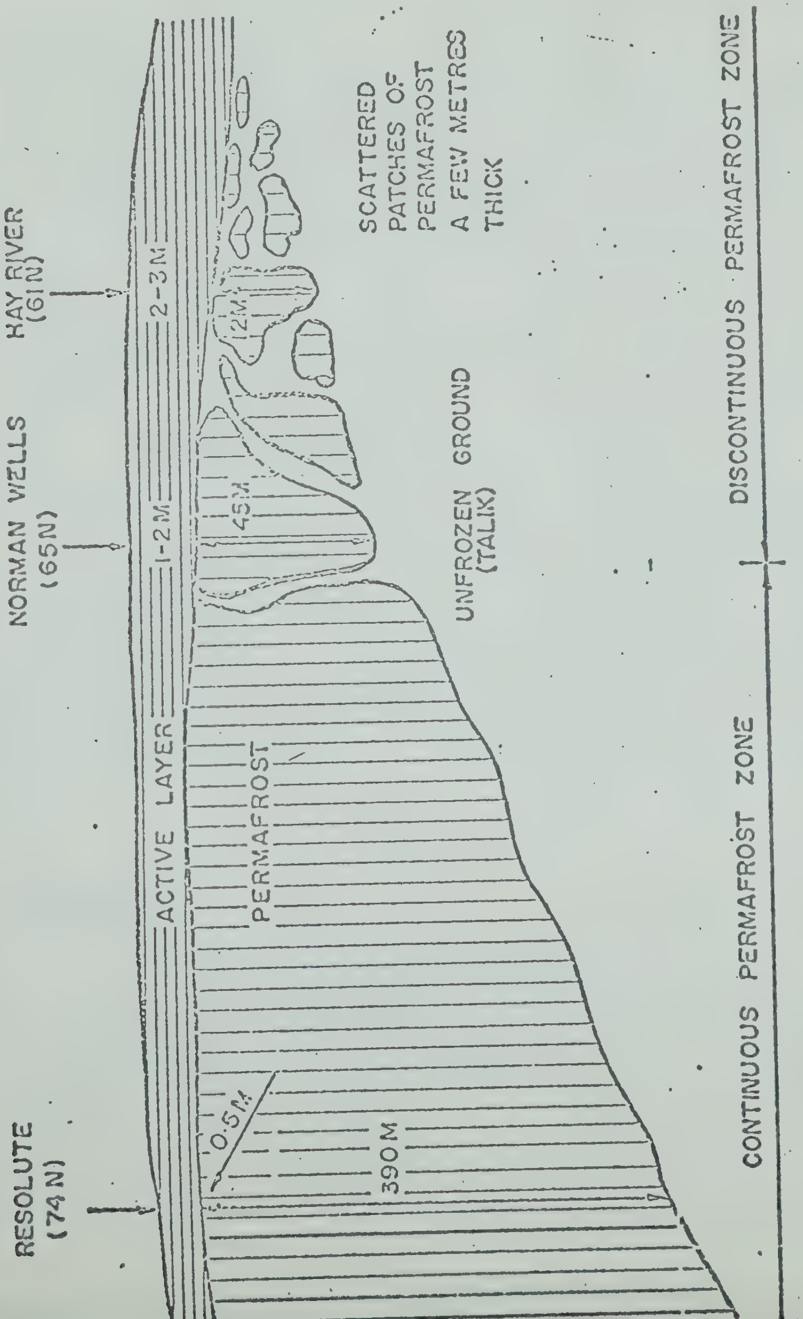

FIGURE 1 PROFILE OF PERMAFROST CONDITIONS

from Brown 1970

it is fitting that the division between the discontinuous and continuous permafrost zone be determined on a temperature basis. The temperature used to divide the two zones is the 23°F isotherm measured below the level of mean annual temperature (Brown 1970, pg. 8). The ground temperature, which is harder to record, was chosen as the boundary isotherm rather than a corresponding air temperature because the mean annual air temperature differs from the mean annual ground temperature by several degrees and this difference is not constant. The complex energy exchange regime at the ground surface, which is influenced by surface and subsurface terrain factors, is such that the mean annual ground temperature is several degrees warmer than the mean annual air temperature.

The objectives of airphoto pattern recognition vary in the continuous zone from those in the discontinuous zone.

The objectives are:

1. to stratigraphically outline terrain units on the basis of minimum depth of active layer;
2. to classify landforms on the basis of terrain sensitivity;
3. to determine key relationships for granular deposits;
4. to choose all sites, by taking into account the delicate ecological balance which exists in this region of the world.

By delineating terrain units on the basis of munimum depth of active layer, the passive method of construction requires the artificial insulation of the permafrost environment to protect the thermal regime. The object is to provide enough material on the surface of the terrain to cause the permafrost table to aggrade upwards. Disturbances caused by route location can be minimized by a thorough understanding of terrain sensitivity as related to various landforms. The identification and location of granular deposits through the use of air photographs is always important to the location engineer.

The engineering solution to problems encountered in the continuous zone is based on minimizing the thermal disturbances effecting the permafrost environment rather than attempting to avoid permafrost affected terrain as previously mentioned in the discussion on the discontinuous zone.

B.1 Topography

The four principle physiographic units discussed in the section on "Topography of the Discontinuous Zone" are also the principle physiographic units of the continuous permafrost zone on the mainland. In addition to these four regions there is one additional physiographic region, the Arctic Archipelago.

The largest structural unit in the Canadian north is the Canadian Shield. Delineating and identifying landforms in the continuous zone is readily accomplished by airphoto interpretation because much of the topography is of glacial origin and the absence of a vegetative mantle allows a clear view of the terrain. The largest plain in Canada, the Western Interior Lowlands occupies a truly continental depression between the Shield and the Cordillera. The dominant physical characteristic of the Mackenzie Lowlands is sedimentary bedrock covered by a relatively thick glacial deposit of predominantly fine grained silts and clays. This area is under intense pressure of development because of the oil located on the Arctic Coastal Plain at Prudhoe Bay, Alaska. The Cordillera consists of a belt of lofty ranges, deep troughs and a broad plateau extending for 1,400 miles and a width of up to 500 miles through the Yukon and British Columbia. Good fill materials can be located, from aerial photographs, in alluvial and glacial deposits, or in bedrock quarries. The Hudson Bay Lowland is a plain underlain by almost flat lying strata, chiefly of Paleozaic age, and a mantle of marine silts and clays deposited during the post glacial submergence of the lowland. The Arctic Archipelago contains several physiographic provinces: the Canadian Shield, an

extensive belt of fold mountains known as the Innuition and the Arctic Coastal Plain of younger sedimentary rocks.

The identification of topographic features containing dry permafrost, is important to the location engineer. Landforms containing coarse-grained material which are well drained are known as dry permafrost. Dry permafrost is not detrimentally affected when thawed because it usually contains noise lenses. The engineering properties of sand, gravel or rock in the dry permafrost state are not seriously affected when thawed. However, if the material is water-bearing clays, silts or muskegs, serious difficulties will be encountered. The requirements for severe permafrost/frost action to alter the land surface are a supply of water, frost susceptible materials and cold temperatures.

Classifications of topographic features in permafrost areas have been attempted by many authors. Bertil Hogbom, a Swede in 1914 and Carl Troll, a German in 1944, presented classification systems for Arctic terrain. A.L. Washburn presented, in 1956, an excellent review entitled "Classifications of Patterned Ground and Review of Suggested Origins". Washburn used the term "patterned ground" to describe the more or less symmetrical forms which included circles, nets, polygons, steps and stripes. His

classification is generally divided into two main categories determined by the amount of sorting. It is interesting to note that the slope gradient is greater for stripes and steps whereas the circles, nets and polygons occur on level terrain. (see Table 1) Washburn's classification attempted to condense many of the Arctic and Subarctic terrain forms into a general system of pattern type.

The ultimate of polygon identification in terrain sensitivity mapping would be the correlation of polygon type, snow cover and air temperature to help predict the thermal properties of the ground. Knowledge of ice-wedge polygon growth and Arctic geomorphology enables the interpreter to obtain data on such items as grain size distribution, depth of active zone, and soil ice ratio. Two main types of polygons exist: depressed centre and raised centre.

Depressed centre polygons are common in the continuous zone and are limited to wet tundra areas such as basins of drained lakes, and abandoned river channels. They are among the most dependable indicators of permafrost. The low centres commonly contain standing water and frequently the higher edges are the site of active frost cracking. Upon thawing and degradation of the ice wedges, the high edges collapse until they are lower than their surroundings

A Classification of Patterned Ground

Table 1

Pattern	Sorted	Unsorted	Ground Slope
Circles	Patterned ground whose unit component, the mesh, is dominantly circular and has a sorted appearance commonly due to a border of stones surrounding finer material. Debris islands are sorted circles occuring amid blocks or boulders.	Mesh is dominantly circular, unsorted appearance due to absence of border stones.	Level
Nets	Mesh is intermediate between circles and polygons; sorted appearance due to a border of stones surrounding finer material.	Mesh is intermediate between circles and polygons, non-sorted appearance due to the absence of a border of stones.	Level
Polygons	Mesh is dominantly polygonal. Border of stones surrounding finer.	Mesh is dominantly polygonal. Absence of a stone border.	Level
Steps	Step-like form with a sorted appearance due to a downslope border of stones embanking an area of finer material upslope.	Steplike form, non-sorted appearance due to a downslope border of vegetation embanking an area of relatively bare ground upslope.	Sloping
Stripes	Parallel lines of stones and intervening finer material perpendicular to the fall line.	Parallel lines of vegetation covered ground and intervening strips of relatively bare ground.	More sloping

and the depressed centre polygons become modified to raised centre polygons. Thus it is apparent that raised centre types tend to develop where degradation of permafrost is in progress. This development is merely mentioned to illustrate a possible technique of formation. Raised centre polygons may develop independently from depressed centre forms; the former being associated with better drained sites. It should be pointed out that gradations exist between the two types, which are a result of many factors, including primarily, surface erosion by water, wind and mass wasting processes, vegetation, type of material, moisture content, rapidity of thaw, growth of ice wedges and age.

Black (1952) refutes statements made by Frost (1951) and Woods et al (1948) which state that polygons are a universal indicator of permafrost. It is useful to note that patterned ground is not necessarily restricted to the Arctic. Many types are found in different types of climate.

The mechanics or reasons for patterned ground are still not understood properly. Frost action is considered to be an important factor in the formation of circles, steps and stripes; whereas polygons are thought to be the result of frost action combined with temperature induced expansion and contraction. The presence of patterned ground

at high altitudes is usually indicative of potential problems with terrain sensitivity.

Topographic position is important in determining the type and degree of permafrost-frost activity. The north facing slopes offer no particular problem if they are well drained. Slope and aspect must be studied locally in great detail to determine the depth of the active layer. Generally the active layer is much thicker on south facing slopes than it is on north facing slopes. From the standpoint of route location it is far better to locate on the north side of a slope because of the increased protection from solar radiation.

The most spectacular topographic feature in permafrost regions probably is the pingo. On an aerial photograph they appear as hill-like formations which are typically conical in shape. They may be as high as 150 feet and their circular or oval bases often measure several hundred yards in diameter. Pingos, because of their ice-cored centres, are a definite indicator of permafrost and, therefore, terrain sensitivity.

At the present time two genetic types of pingos are recognized. Dr. Fritz Muller, who conducted some systematic investigations, classifies them as the "open" or

East Greenland type and the "closed" or Mackenzie type.

The Greenland type is an "open" ice-water system in which the core may contain, in addition to ice lens, unfrozen water. This type is sometimes termed a hydrolaccolith because the source of water is neither juvenile nor ancient but identical to surface water under hydrostatic pressure. (Scheidegger 1970) The destruction of East Greenland pingos results from (a) the rupturing of the top during growth; (b) the degradation of the ice by the penetration of summer warmth through the weakened organic cover; and (c) the sub-or intra- permafrost water rising and thus melting the ice body.

The origin of the Mackenzie Delta pingos is explained as follows: a small shallow lake is drained rapidly and the permafrost penetrating from the surface and surrounding thawed bulb beneath the lake causes the trapped material under pressure to undergo a stress release in the upward vertical direction. Their destruction is largely brought about by ice core degradation, naturally or as a result of man's activity disturbing the thermal balance. The explanation of formation explains why pingos in the Mackenzie Delts occur in the geometric centre of small lake basins. There are over 1,400 pingos in the Mackenzie Delta. (Hamelin and Cook 1967).

B.2 Vegetation

The continuous zone can be divided into three climatic zones: (1) the forested zone; (2) the Arctic zone which is north of the treeline, and (3) the polar desert. With increasing latitude the decrease in vegetative cover corresponds to an increasing permafrost profile.

The forested zone is an area in which there are very few surface manifestations of the underlying ground condition. The coniferous forested zone continues up the Mackenzie Valley Lowland to within 20 miles of the Arctic coast. The reason the treeline extends so far north in the Mackenzie Valley is because of the protection to the low elevation of the valley by the Richardson Mountains on the west and the Cariboo Hills to the east. In the forested part of the delta, spruce is dominant; poplar, birch and thickets of alder are also present. From aerial photographs many meadows are observed to be unable to support tree growth. The conditions of the ground in these areas should be noted to determine if there is a shallow active layer. North of the tree line in the Arctic zone, the vegetation consists of mosses, grasses, sedges and heaths with widely scattered scrub willow and alder.

The vegetative surface cover of trees, shrubs and low plants is of threefold importance in permafrost areas:

(1) vegetation acts as an insulator

(2) vegetation may be utilized for local construction materials such as piles, logs and saw timber

(3) vegetation can be used as an indicator of particular soils, ground water, wind, snow cover conditions or soil-ice ratio.

Vegetation has a direct influence on permafrost distribution. Local vegetation may help to reflect terrain sensitivity. Tables which suggest a correlation between vegetal type and depth of active zone must be used with some caution. Locally, the distribution of a plant can be influenced by a single limiting factor. Regionally, there does not appear to be any correlation between vegetation and permafrost since the cover type established on a particular site reflects the total effect of environment on which climate and subsurface material are only two factors. Airphoto interpretation techniques of vegetation, although dependent on regional distribution, require assessments on a smaller or local scale supplemented with ground truth

to be of practical significance.

To further complicate the already intricate problem of vegetation in the North, forest fires tend to alter the existing patterns.

Permafrost is a controlling factor only when it occurs at a shallow enough depth to influence soil drainage, stability or temperature within the zone of root growth. Stoeckler (1949) was able to correlate cover type, topographic position, slope, aspect and drainage with soils and permafrost conditions and airphoto patterns for limited areas.

As mentioned, soil types, permafrost and terrain sensitivity are indicated or can be inferred from vegetation only on a local basis. Table 2 can be used as an approximate guide to the relationship of vegetal type, depth of active zone and subsurface conditions. Certain vegetation associations have been correlated with subsurface conditions and permafrost occurrence and, therefore, when considered together with topographic position, soil texture and drainage can be used as reliable indicators of detrimentally frozen ground. Correlations of this type are meant only as a guide and should be field checked.

TABLE 2

Vegetation as a Preliminary Permafrost Indicator

Type of Vegetation	Estimated Minimum Depths to Permafrost	Characteristics of Underlying Ground
Willows	8' - 10'	Ground water that freezes for only a short time; permafrost is likely to be absent.
Pure stands of mature Aspen or White Birch	4'	Shallow sporadic permafrost.
Mixed Willow, Alder, and White Birch	3' - 4'	Well drained.
Pure stands of Balsam, Poplar	3' - 4'	
Mixed White Spruce and Balsam-Poplar	3'	
Pure stands of White Spruce	2' - 3'	Wet ground and high permafrost table.
White Birch	2' - 3'	Thawed ground either in permafrost or between the permafrost and the frozen ground.
Mixed White & Black Spruce	1' - 2'	
Black Spruce Tamarack	1'	High permafrost table.
Hummocky tundra (Niggerheads)		Permafrost table near the surface, poor drainage and generally a waterlogged condition.
Aspens		Dry unfrozen, south facing slopes.
Pine and Fir		Well drained granular soil, lowered permafrost table.
Peat plateaux & palsas	**1' - 2'**	**Organic active layer covering silty clay with ice lenses.**

B.3 Drainage

Drainage networks or the lack of the same are a good indication of permafrost soils. The regional drainage plan is little altered by the presence of permafrost. (Frost 1960). Locally, the drainage plan is altered considerably due to the presence of permafrost. It is this local variation in drainage which is important in terrain sensitivity analysis.

A common effect of permafrost is that the gully sides due to orientation may not be symmetrical even though the materials are similar. This variation can be explained by the aspect of the slopes. South facing slopes, receive more solar radiation than north facing ones and as a result have a deeper thaw into the slope face allowing more erosion. Gully shape characteristics are therefore more developed on south facing slopes and may actually be depressed on north facing slopes. In active portions of gullies where the slope face is still developing, there is a tendency to vertical or U-shaped cross sections, regardless of material because of the cohesion of frozen soils. (Pilhainen).

For the most part, frozen soils erode by thaw which can be induced either naturally or through activities of man. Thermal disruptions of existing perennially frozen

ground are usually associated with some disruption of the insulating cover of vegetation. If these effects are recent or active, striking deviations from normal growth characteristics are observed. For example, living tilted trees on lakes or stream edges indicate active erosion. If the tilted trees or "drunken forests" continue to grow they will grow vertically upwards and the result is a bend in the trunk.

Additional consequences of thermal disruption are differential ground subsidence due principly to the thawing ice in perennially frozen soil which may vary considerably. In extreme cases, the random subsidence may result in ponds or even lakes. This phenonmenon is termed thermokarst and lakes with such origins have been termed thermokarst lakes. Beaded streams are another drainage feature which indicates permafrost. Beaded streams are particularly prevalent in the continuous zone where blocks of massive ground ice melt in the stream bed forming enlargements along its course. (Brown 1970).

A common type of gully system in permafrost is "button drainage" which is also easily recognized on photos. Button gullies are usually found in association with polygon areas which are in the initial stages of thaw.

In the Arctic and Subarctic, solifluction is perhaps the most active agent of erosion and a definite indicator of terrain sensitivity. The term was introduced by Anderson in 1906 and subsequently defined by Washburn (1950) as "the viscous flowage by gravity of unhomogeneous material" flowing from high to lower ground. The material which is moving down a slope as small as 2° or 3° consists of non-sorted debris containing rocks, mud, clay and liberal amounts of water behaving enmass as a plastic solid. Flow will occur over the permafrost table when gravitational shear stresses exceed the yield limit of the mass and will stop flowing when a decrease in water content causes an increase in the material's consistency or when the stress has fallen below the yield limit because of the mass reaching a slope of a smaller angle.

In areas where vegetation is sparse the soil flows usually extend unbroken for considerable distance down the slope. The channels between the flows appear darker because of higher moisture content and vegetative cover. The very slight differences in elevation between the flow ridges and the intervening swales affords protection to plants. Rocky slopes are marked with long streamers of rock slabs and fragments. The features just described

are easily detected on good quality aerial photography. It should be understood that these markings indicate a very sensitive terrain which is exceptionally unstable during the warm periods. Any engineering construction should avoid slopes which indicate this feature.

C. Conclusions

1. An aerial panchromatic photograph represents a tremendous amount of data. It is generally accepted that the most practical imagery is stereoscopic panchromatic aerial photography.

2. Useful terrain analysis is dependent mainly upon the individual extracting the information.

3. The mental association and recognition of a feature in a stereoscopic pair of aerial photographs is directly related to the individual's background and experience in the Arctic.

4. The correlation of topographic, vegetative and drainage characteristics evident on aerial photographs to delineate permafrost affect terrain or terrain sensitive land units in the continuous zone should also consider other factors which affect the distribution of permafrost.

5. Similar terrain units identified on the basis of the three terrain characteristics mentioned should not be assumed to accurately represent the ground conditions without field checking selected sites.

6. Remote sensing reduces the high cost of Arctic site location which is characteristic of conventional ground survey techniques.

7. Terrain sensitivity indicators decrease from high Arctic latitudes to lower latitudes in the Subarctic.

8. Preservation of the thermal regime and subsequently the ecology is possible by delineation of terrain sensitive regions on photo mosaics and the subsequent protection of these areas.

9. The identification of ice rich soils and their associated thermal characteristics can best be achieved by the stereoscopic inspection of available panchromatic photography.

10. Panchromatic photography of the Canadian Arctic is available from the National Airphoto Library, 615 Booth Street, Ottawa. This photography is ideal for preliminary terrain analysis at its scale of 1 inch equals 1,000 feet.

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